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CONCEPTUAL MODEL OF A SMART INTEGRATED EDUCATIONAL ENVIRONMENT

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Abstract: At present, we are witnessing a trend of gradual transition from traditional technologies of mass education to in-depth, practice-oriented training of professionals. In this regard, educational models based on the application of smart technologies for engineering information-educational spaces, which provide for the individualization of learning trajectories, flexibly combining the requirements of the employer with the possibilities of competence-oriented educational programs, are becoming increasingly important. The goal of the current study is to develop innovative educational programs of higher education through the integration of the components of the educational process into one information-educational space with the use of smart technologies, as well as to develop information search and logical-semantic algorithms for generating a variety of educational and methodological information, helping to form the most relevant educational and organizational and managerial content and organize the learning process under the predetermined parameters of specialist training in a particular subject area. As a result of the conducted research, the authors present their attempt at systematizing the variety of components of an information-education environment and conduct their ontological engineering in order to identify and subsequently integrate all components in the form of a global learning ontology.

Keywords: information-educational space, semantic modelling, digital repository, professional standard, educational standard, ontology, concept.

Introduction

The continuously expanding nomenclature of modern professions and, as a result, the explosive growth of educational content generated for their mastery, even despite the use of the latest digital learning technologies, often leads to information "chaos", in which a potential employer has difficulties understanding the large variety of educational programs differentiated by areas, levels, forms, and profiles of training, while for the graduate of the educational institution, it is increasingly difficult to objectively assess their professional capabilities and correctly determine their place in the labour market.

A solution to this contradiction, we argue, can be the development of an integrated information-educational learning environment of a new type that combines different groups of ontologies related both to the content of education and to the overall infrastructure of its development and improvement. The main idea of creating such a learning environment is to thoroughly describe and systematize as many diverse elements of the information-educational space as possible and to build a certain global ontology of learning on the basis of such an environment.

In order to develop the educational content of an educational program focused on mastering the knowledge, skills, and labour operations (abilities) specified in professional standards with consideration of the competencies formulated in these standards, it is necessary to provide a detailed description of both the objects of the generalized IES model and their interactions. Such a description makes it possible to flexibly and adaptively generate different educational program components regulated by the educational standard for certain types of professional activities, groups of classes, generalized labour functions, and labour functions regulated by professional standards. Such a task seems to be extremely important, and its solution is impossible without applying special algorithms of engineering based on intellectual technologies.

Scientific literature (Gasparian & Telnov, 2016; Gasparian, 2014) presents a concept and substantiation of the development of a flexible integrated system for engineering the educational content of an individual learning environment on the basis of the information-educational space (IES) model as well as the use of smart technologies and the implementation of such a system. Research (Zinder, 2015a, 2015b; Telnov, 2010; Telnov et al., 2015) thoroughly examines the issues of creating an IES model and offers a detailed analysis of its main components.

One of the possible approaches to the development of an integrated information model of educational content engineering might be the approach based on the Dublin Core metadata system (DCMI, 2012, 2020), which is considered by many researchers to be a promising instrument for the formation of descriptive metadata for a wide range of digital objects.

According to the recommendation RFC 2413 (Weibel, Kunze, Lagoze, & Wolf, 1998), all the Dublin Core elements described in the list can be divided into three groups: elements related to the content of the resource - Content (Title, Subject, Description, Type, Source, Relation, Coverage); elements describing the digital resource in terms of intellectual property - Intellectual Property (Creator, Publisher, Contributor, Rights); elements related to a particular instance of the resource - Instantiation (Date, Format, Identifier, Language).

To enter any digital objects into the repository, it is necessary to form a detailed description of each object (whether it is a document, text, test assignment, film, presentation, image, sound element, or any other digital resource) on the basis of the proposed DC methodology. Such a description, including the use of metadata dictionaries, will, in our opinion, automate the process of generating individual learning modules formed or constructed from a set of educational objects.

Methods

Analysis of modern approaches to semantic modelling of the educational process as a whole and its individual components gives us the opportunity to identify the main stages of engineering an effective educational program, such as developing a conceptual model of a smart integrated educational environment by formalizing the elements of integrated information-educational space, coupling the ontologies of professional and educational standards, systematizing and organizing the elements of a digital repository, developing algorithms for generating educational and methodological and organizational and administrative content of the smart integrated educational environment, as well as testing the proposed methodology in a real practical example of developing the educational and methodological support for an educational program (Trembach, 2016; Telnov, 2014).

Based on the analysis of the structures and methods of creating ontologies, we can conclude on the expediency of including concepts that allow describing both the static state and dynamic changes in IES objects into the ontology used to ensure the semantic interoperability of IES services. Each concept of an ontology is characterized by a certain set of attributes (properties). Mandatory attributes for each concept include concept identifier, concept name, concept creator, concept subject (information), publisher, date of creation, concept type, concept representation format, source (related or related resource as data source), concept content language, link (links to related concepts, keywords defining related concepts and synonyms), geographical coverage, and audience (concept users).

The possible types of concepts can be “Documents”, “Participants in the learning process”, “Learning outcomes”, and “Learning resources”.

Let us explore the methods of ontological engineering that can be applied to create IES ontologies. The simplest form of ontology storage is an OWL file. When reading such a file in RAM, a model (set of statements) is created, and further work is performed with it. The obvious disadvantage of this approach is the rising memory consumption, as well as a significant increase in the time of loading OWL files as the volume of metadata contained in the ontology grows. The need to use special language tools to retrieve metadata stored in ontologies necessitates the construction of ontology repositories based on DBMS.

From the point of structural features, the best suited for storing ontologies are graph databases. In this case, graph vertices can be used to store ontology concepts, and graph edges can be used to store relationships between concepts. Vertices and edges can contain any set of attributes. An edge always has a start node, an end node, a type, and a direction. Graph DBMS began to be actively used with the development of social networks and are now widely used, for example, to solve problems related to the search for fraudulent and suspicious transactions in payment systems. In such tasks, it is important to quickly find vertices associated with the original one.

Relational DBMS, compared to graph DBMS, has higher efficiency of data retrieval based on the values imposed on the attributes (the task of selecting the nodes of the graph directly, without accounting for the relationships). Graph DBMSs are more efficient in queries that take into account relationships between nodes.

A study by Boichenko, Korneev, and Kazakov (2015) describes an approach for the organization of semantic data retrieval, taking into account the advantages of both graph and relational DBMS. A set of interrelated concepts reflecting the semantics of the subject domain is stored as a graph in the above case. Data is stored in relational Tablachs containing a significant number of records. Initially, the query selects vertices of the graph according to the specified conditions imposed on the relationships between concepts. The selected vertices contain attribute values that are used to search for records in the relational Tablich. Search by graph model is organized by means of DBMS Neo4j (Barrasa, Hodler, & Webber, 2019) and the search of records in relational Tablich – by means of MySQL DBMS.

In this case, special attention should be paid to ORACLE DBMS, which today can be attributed to the class of object-relational. ORACLE 11g (McLaughlin, 2015) uses the mechanisms united by the term Semantic Technologies. Version 11g provides the ability to export and import OWL-structures and supports OWLPrime ontology description language, which includes features for

- creating an ontology structure (class, subclass, property, subproperty, domain, range, type);
- specifying the characteristics of properties (transitive, symmetric, functional, inverse functional, inverse);
- comparing classes (equivalence and disjointness);
- comparing properties (equivalence);
- comparing entities (same, different);
- setting limits on properties (hasValue, someValuesFrom, allValuesFrom).

OWLPrime is supported by over 50 rules, which are used in the process of logical output. A rule consists of a condition (“if”), a filter (condition), and an output (“then”). ORACLE 11g implements the feature of making custom rules using the OWLIF language (IF-THEN constructs). Certain restrictions can be set on the rules that a user can create. For example, it is possible to specify that a user can only create logical output within a subClassOf hierarchy, and the number of output steps can be limited.

Queries to retrieve information from ontologies in ORACLE 11g are performed using the SPARQL language. The user-created output rules in SPARQL queries are connected using the SEM_RULEBASES construct.

Results

As an example of the implementation of the proposed generalized model for engineering the educational content of an individual learning environment, we describe IES concepts using, among others, the elements of Dublin Core metadata. At the same time, for a complete and correct description of the structure of IES concepts, it is advisable, in our opinion, to use a limited set of metadata consisting of the following elements: Identifier, Title, Creator, Subject, Description, Publisher, Date, Type, Format, Source, Language, Relation, Coverage, Audience. Naturally, some of these concept description elements are standard and can be applied to any IES concept description. Therefore, in order to avoid repeating the descriptions of standard elements, let us describe them in one table. A possible list of standard elements and their description for any IES concept is given in Table 1.

Table 1.

List of Standard Elements for Describing Any IES Concepts.

Title	Description of the attribute
Identifier	Concept code
Title	Concept title
Creator	Name of the developer organization, full names of the developers
Description	A link to the full description of the concept in open access
Publisher	Organization responsible for providing the resource to users
Date	Date of approval in the YYYY-MM-DD format
Format	File format with the text of the document posted through the link specified in the Description attribute value
Language	The language of the concept content (two- or three-letter language tags with optional subtags)
Coverage	The designation of the geographical name of the place of use of the concept in accordance with the Thesaurus of Geographical Names (TGN)
Audience	The list of concepts of the type “Participants in the learning process”, “Documents”, “Learning outcomes” and “Educational resources” (linked with)

Further on, we provide an additional description of IES concepts using the metadata set composed of the elements Subject, Type, Source, and Relation.

The “Professional Standard” concept contains a general description of the document as a whole, including such characteristics as its code and name of the standard, its association with the type and purpose of the type of professional activity, as well as descriptions of the affiliation of the document with various topics in accordance with the control dictionaries and formalized classifications. A possible structure of the concept is presented in Table 2.

Table 2.

Additional Description of the “Professional Standard” IES Concept.

Title	Description of the attribute
Subject	Name of the type of professional activity The main goal of the kind of professional activity Occupational groups according to the All-Russian Classifier of Occupations (ACO) Type of economic activity according to the All-Russian Classifier of Economic Activities (ACEA)

Type	Document
Source	Reference(s) to publicly available source(s) of information about the standard (is part of)
Relation	The list of the formed (included) generalized labour functions (GFL)

The "Generalized Labor Function (GLF)" contains the code and phrasing of the GLF, as well as a description of the GLF's association with various topics according to control dictionaries and formalized classifications. A possible structure of the concept is presented in Table 3.

Table 3.

Additional Description of the "Generalized Labor Function (GLF)" IES Concept.

Title	Description of the element
Subject	Qualification level code Possible job titles for the generalized labour function Education and training requirements for the generalized labour function Requirements for practical work experience for the generalized labour function Special conditions for admission to work for the generalized labour function Additional characteristics for the generalized labour function. Basic occupational group according to the ACO Additional characteristics for the generalized labour function. Basic positions in accordance with the unified qualification reference book for managers, specialists, and office workers (UQR) Additional characteristics for the generalized labour function. Basic specialities in accordance with the All-Russian Classifier of Specialties in Education (ACSE)
Type	Learning outcomes
Source	Link to the professional standard in open access, which prescribes this GLF (is part of)
Relation	The list of the formed (included) labour functions (LF)

The "Discipline" concept contains information about learning goals and objectives, educational material, assessment tools, and the developed competencies and learning outcomes for the discipline. A possible structure of the concept is presented in Table 4.

Table 4.

Additional Description of the "Discipline" IES Concept.

Title	Description of the attribute
Subject	Aims and purposes of the discipline Keywords Topics and short abstracts of topics Competences to be formed Learning outcomes of the discipline
Type	Educational resource
Source	Reference(s) to the source(s) of information about the discipline (curriculum, educational program) in open access (is part of)
Relation	The list of the formed (included) codes of competencies and codes of assessment tools that test the development of the competencies

The "Base Enterprise" concept contains detailed information about the sphere of activity of the enterprise that serves as the base for the implementation of the educational program and with which the educational organization has an agreement on cooperation. A possible structure of the concept is presented in Table 5.

Table 5.

Additional Description of the "Base Enterprise" IES Concept.

Title	Description of the attribute
Subject	Names of areas of professional activity Names of spheres of professional activity Types of tasks of professional activity Subject matter of the agreement on cooperation with an educational organization Types and forms of interaction with the educational organization Special conditions of collaboration
Type	Participants in the educational process
Source	Reference(s) to the source(s) of information about the basic enterprise in open access
Relation	The list of educational organizations with which the enterprise has contract relations

Additional descriptions for other IES concepts can be given in a similar manner. For instance, additional descriptions for concepts of the "Document" type can be provided for such concepts as educational standards, competency passports, educational programs, and curriculum. The concept of "Educational Standard" contains a general description of the document as a whole, including such characteristics as its code and name of the standard, its connection with the areas, spheres, and types of professional activity tasks, as well as the description of the main parameters of the educational program. The "Competency Passport" concept contains a detailed description of both the competence itself and the indicators of its achievement through learning outcomes, as well as references to the disciplines that form this competency and the assessment tools that can be used to test its development. The "Educational Program" concept contains a general description of the educational program, including such basic characteristics as the code and name of the direction of training (speciality), the areas, spheres, and types of professional activity tasks, competencies to be formed, the curriculum, as well as the resource provision of the educational program. The "Curriculum" concept contains a general description of the document, including the codes and names of the direction and profile of training, the year of enrollment, as well as the distribution of disciplines included in the curriculum by periods of study, their volume in credit units, and associations of the disciplines with the competencies formed.

Descriptions of concepts of the "Learning Outcome" type can be made for such concepts as qualification level and labour function (LF). The "Qualification Level" concept contains the code and name of the qualification level, as well as descriptions of resource provision. The concept "LF" contains the code and formulation of the LF, as well as the list and formulation of knowledge, skills, and labour actions indicating the mastery of this labour function.

Descriptions of concepts of the type "Learning Resource" can be developed for such concepts as educational material and assessment tools. The "Educational material" concept contains detailed information about the educational resource used in the learning process, including the form of interaction between the student and the teacher. The "Assessment Tool" concept contains detailed information about the assessment tool used in the learning process, including the form of interaction between the student and the teacher when using this assessment tool.

Descriptions of concepts of the type "Participants of the educational process" can be made for such concepts as an educational institution, teacher, and student. The "Educational Institution" concept contains detailed information about the educational institution and educational programs, as well as ongoing research. The concept of "Teacher" contains detailed information about the teacher, the disciplines taught by them, areas of their scientific interest, portfolio, and other significant elements and achievements. The concept "Student" contains detailed information about the student, and their full portfolio, including the direction of training or speciality, the level and form of training, curriculum, and educational program, as well as information about the progress, achievements, changes in the place of training, and other significant events in the educational and extracurricular activities.

Conclusion

If we assume that the wording of learning outcomes (knowledge, skills, and abilities) from academic disciplines partially or completely coincides with the wording of labour activities, knowledge, and skills from professional standards, there is a possibility to generate educational content in a flexible and adaptive manner. For example, when specifying a certain job function, it is possible to determine the required learning outcomes (including the professions and generalized labour functions for which they are needed) and select the necessary competencies through qualification requirements, thus determining the most relevant applicable educational standard and generating a set of educational resources (presentations, lecture texts, case studies, workshops, textbooks, books, articles, audio and video materials, assessment tools, simulators, training simulators, and other educational resources).

As a result of the conducted research, the present paper proposes a possible structure (a set of types of concepts and associations) of an ontology for resolving the problems of ensuring the semantic interoperability of IES services. Further work on the approbation of the specified structure is planned to be carried out. According to the results of the approbation, the described ontology structure will be specified, meaning that new objects and connections may be added to it.

The present study demonstrates the possibilities of using graph and relational DBMS for creating ontology repositories. Based on the above, it can be concluded that, at present, the most appropriate tool for creating ontology repositories used to ensure IS interoperability is ORACLE DBMS version 11g. However, it should be noted that the preconfigured logical inference rules (discussed above) will not be as effective in working with IS ontologies. This is due to the fact that these rules are more focused on work with the ontologies in which the vertices are connected as a class and subclass. The ontologies that can be used in IES contain vertices linked with, for instance, "Association" and "Action" types of links. In this case, processing such nodes requires custom output rules, which were mentioned earlier.

As a positive trend, it should be noted that mechanisms for working with ontological structures are now appearing in both relational and graph DBMS. To date, as mentioned above, such mechanisms have received the greatest development in ORACLE DBMS version 11g under the name Semantic Technologies. It can be predicted that these mechanisms will be further developed and, at some point, it may become more convenient to create ontology repositories by means of other DBMS (for example, the graph Neo4j) or use the technology of combined use of graph and relational DBMS (Boichenko, Korneev, & Kazakov, 2015).

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